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UNDERGROUND GASIFICATION OF COAL IN USSR

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INTRODUCTION

There is very little literature in Polish on the problem of underground gasification of coal.(1, 2, 5, 6) To fill this gap, information has been gathered concerning this subject on the basis of available literature. (3, 4)

Underground gasification of coal is applied on an industrial scale in the Soviet Union only. The Soviet Union is ahead of other countries in the development of this method of utilizing coal, and has long since gone beyond the experimental stage in the use of this method. Only recently was experimental work begun in the US, Belgium, and Italy. (5, 6, 10)

The underground gasification of coal is the name of the process of complete conversion of the organic matter of coal deposits into a gas containing combustible components, without removing the coal from the deposit. In some cases, additional equipment is used for the separation of tar-like substances derived from the partial degasification of the coal. Gasification may be accomplished with the aid of air, a mixture of air and steam, air enriched with oxygen, and a mixture of oxygen and steam. This process takes place under pressure approximating that of the atmosphere. The gas obtained is composed of the products of gasification and degasification of coal, and also of carbon dioxide, which is forced during the oxidation of the coal substance. The theoretical calorific value of the gas is about 2,800 kilocalories per cubic meter. It is about 1,350 kilocalories per cubic meter with the application of oxygen, and 890 kilocalories per cubic meter if air is used.

Underground gasification of coal opens new ways for the utilization of coal, especially where the usual mining methods are either difficult or uneconomical. This method would therefore be applied primarily to deposits

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of poor-quality coal, to thin, steeply dipping layers, to deposits with a tendency toward spontaneous combustion, and deposits containing large quantities of rock.

The investment costs of an underground gasification plant are placed at about 60-70 percent of the expense of building an ordinary generating station, and consist mainly of the installation of blasting equipment and power supply equipment. Costs for production of gas by the underground gasification method are placed at 25-30 percent of those for generator gas, because of lower investment, operation, and labor costs.

HISTORICAL DEVELOPMENT OF THE PROCESS OF UNDERGROUND COAL GASIFICATION

The idea of underground coal gasification was first proposed by the famous Russian scientist D. J. Mendeleyev in 1888. In 1912, W. Ramsey, undoubtedly informed about Mendeleyev's work, also became an advocate of this idea. At the end of the Revolution in Russia, the possibilities of such underground coal gasification began to be considered, and on the basis of directives given by the Supreme Soviet USSR, a commission for problems of underground gasification was set up under Glavugol' in 1931. In 1932, the construction of the first experimental station was begun in Lisichansk. In 1933, an underground gas generator was built in the Moscow Basin. An All-Union Podzemgaz bureau was also created in 1933 to coordinate all the work connected with underground coal gasification and to direct the work of the existing experimental stations. In 1936, the work passed from the experimental stage to application on a semitechnical scale. In that year, Podzemgaz already employed 1,500 workers, including 150 specialists. In the period from 1933 to 1939, three different methods were applied, depending on the types of coal deposit, and positive results were obtained. Parallel to the work of the experimental stations, work was conducted at the Academy of Sciences USSR and the the Donets Scientific Research Coal Institute, investigating the chemical and physical processes accompanying underground gasification.

METHODS OF UNDERGROUND GASIFICATION AND CONSTRUCTION OF UNDERGROUND GENERATORS IN THE USSR

The methods of underground gasification used thus far may be classified as follows:

Shaft Methods	Drilling Methods
Gasification with crushing the coal layer	Drill method
Gasification without crushing the coal layer	Filter method
Flow method	

The shaft methods require a certain amount of preparatory underground mining operations, which are sometimes extensive. In the drill method, openings are merely drilled from the earth's surface to the deposit.

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Gasification With Crushing the Coal Layer

This method, mainly of historical importance, was one of the first applied, and was carried out by engineer I. Kirichenko in Lisichansk. The principle of this method is given in Figure 1.

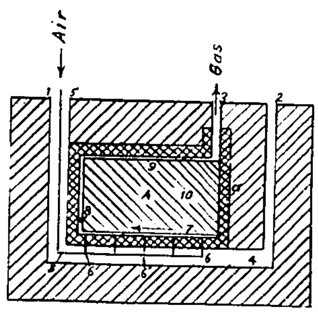

Figure 1. Diagram of the Underground Gasification of Coal by the Kirichenko Method

A block of coal A was separated from the layer. It was bounded by the decending shaft 1, the ventilation shaft 2 and the fire shaft 3. The shafts 1 and 2 were connected by the tunnel 4. The block was separated from the neighboring coal by a strong rock wall a. Through the pipes 5 a blast of air and steam was sent to the nozzles 6, which were located in the tunnel 4. The nozzles reached into the igniting tunnel 7, where wood was initially placed and ignited under a weak blast. The gases that were formed passed to the shaft 8, and hence to the fire tunnel 9. Through the fire shaft 3 the gases reached the earth's surface. The crushing of the layer occurred in the course of the block's burning as a result of explosions of charges of powder which was previously placed in the openings 10, drilled parallel to the diagonal of the block. In the case of Professor Fedorov's proposal, the explosions did not occur as a result of the block's burning, but were ignited electrically from the earth's surface. In the experiments in Shakhty and the Moscow Basin, the so-called chamber method was used (according to Kuznetsov's method).

In this case also, a block of the coal layer was isolated by means of a wall, and the air and gas tunnels were placed on both sides of the block.

Figure 2 is a diagram of the installations used for production by the chamber method. Several chambers are made in the layer, each filled with coal that has been crushed by explosives. These chambers are connected with parallel tunnels which serve to supply air and take off the gas.

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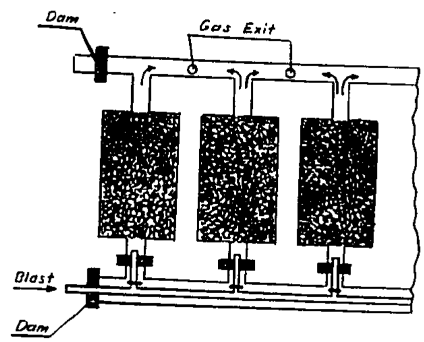

Figure 2. The Chamber Method of Underground Gasification

This method was applied in Shakhty for over 2 years. The course of the process was studied with chambers of varying dimensions, variously placed in the layer. Fuel gas was obtained in varying quantities, depending on the conditions of underground gasification. This gas had the following composition and properties:

Table 1

CO_2	CH_4	H_2	CO	N_2	Calorific Value
12-18%	1-2%	6-12%	10-19%	--	750-1,100 kcal/cu m

Table 2 presents the percentage composition of gas produced continuously over a 2-week period, under the same conditions.

Table 2

CO_2	CO	H_2	CH_4	N_2	Calorific Value
12.6-18.0%	11.5-30.2%	15.0-24.1%	0.3-1.8%	33.4-54.5%	1,080-1,720 kcal/cu m

The production costs was given as one fifth of the costs of gas generated by the usual method. In the above-mentioned methods, the authors attempted to create underground conditions approximating those used in ordinary gas-generating processes (a loose layer of coal); it appeared, however, that underground conditions made this impossible. As coal gasification and burning proceeded, vacant spaces were formed which failed to fill up either with waste rock or with coal loosened by the explosions. Numerous crevices and passages were

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formed, through which part of the air escaped from the gasification area. Part of the air was thus completely, lost, and part entered the fire tunnel, where it caused the burning of the gas, insofar as gas was formed at all.

Gasification Without Crushing the Coal Layer

In the Moscow Basin, an attempt was made to gasify an uncrushed block of coal over 9 meters in width and containing over 250 tons of coal. Natural crevices and the deposit were utilized for the passage of the gas.

The block was ignited and the blast was introduced through the inside of the isolating wall, while the gas was received through the opposite wall. It turned out that the isolation was faulty, and the burning process was unusually slow, so that after 2 weeks only a small portion of the block destined for gasification had been consumed. The gas contained less than 10 percent carbon monoxide, and 10-14 percent unused oxygen.

Another attempt to gasify an uncrushed block was made in the Kuzbass. This block, isolated from the remaining coal, was about 18 meters long, 7 meters wide, and 4.5 meters thick, and contained over 1,000 tons of coal. A tunnel was made to run along the length of the layer, and was connected with the earth's surface by two shifts, one for supplying air, and the other for receiving gas. The coal in the tunnel was ignited, and a blast of air of about 3,000 cubic meters per hour was applied. No oxygen was added. Gasification was conducted under constant conditions for 30 days, during which over 200 tons of coal were gasified. Table 3 gives the percentage composition and the calorific value of the gas obtained.

Table 3

CO_2	CH_4	H_2	CO	N_2	Calorific Value
10-15%	13-35%	10-55%	5-10%	10-40%	2,200-4,400 kcal/cu m

After 30 days, one level of the tunnel collapsed but the production of gas was continued . The experiments were complete when the entire block was burned. This test showed that under the conditions described above, only degasification of coal took place, after which coke was left underground.

The Flow Method

Skav, Matveyev, and Filipov, workers of the Donets Scientific Research Coal Institute, developed a method which differs considerably from those hitherto described, and which was employed in 1934. This method has been used in Gorlovka since 1935 on an experimental scale, and since 1938 on an industrial scale, with considerable success. The principles of this method were covered by two Russian patents of 1935 and 1938, and have been made available in many publications. The diagram of an installation operating by this method is shown in Figure 3.

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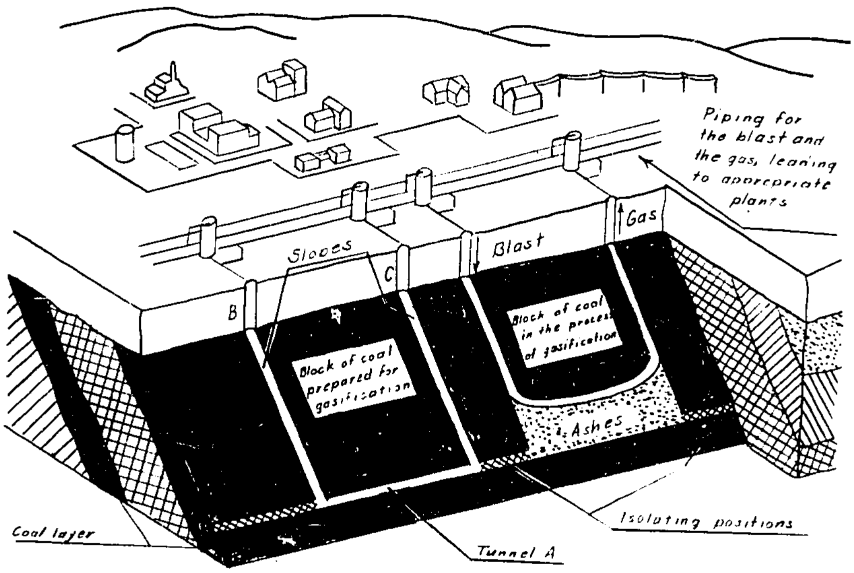

Figure 3. Gasification by the Flow Method

Two or more slopes running along the elevation of the layer (the diagram shows four), over 60 meters in length and having a diameter of 60 centimeters, are spaced about 90 meters from each other, and are connected at the bottom by a horizontal tunnel A.

On the left side of the drawing, a rectangular block of coal is seen, separated from the rest of the deposit and ready for gasification. The shafts B and C connect the slopes with the earth's surface. The test blocks contained from 11,000 to 12,000 tons of coal; the gradient was 75-80 degrees. The coal is ignited in the tunnel A. Air, which may be enriched by oxygen, is brought in through the shaft B. The rising gases are carried off through the shaft C. The coal layer undergoes gasification along the tunnel A, after which the reaction area slowly moves through the layer. The ashes, and waste rock drop, and accumulate beneath the reaction area. This assures the maintenance of the fire head in a state free from ashes, and an easy access of air to the reaction area, as rocks dropping from the roof cannot prevent the air from reaching the coal destined for gasification. The blocks are usually 90-180 meters wide. In the case of blocks of greater width, it is desirable to space the shafts 90-140 meters from each other, so that eventually the deposits is divided into a number of sections which are exploited simultaneously. The authors state that this method should prevent blockages due to the collapse of the roof. On the right in Figure 3 is shown a block of coal after undergoing a certain period of gasification. In the fire tunnel A, three zones should be distinguished. Figure 4 shows the course of the reaction in an experimental block 7.5 meters wide. Air without additional oxygen was used for the blast.

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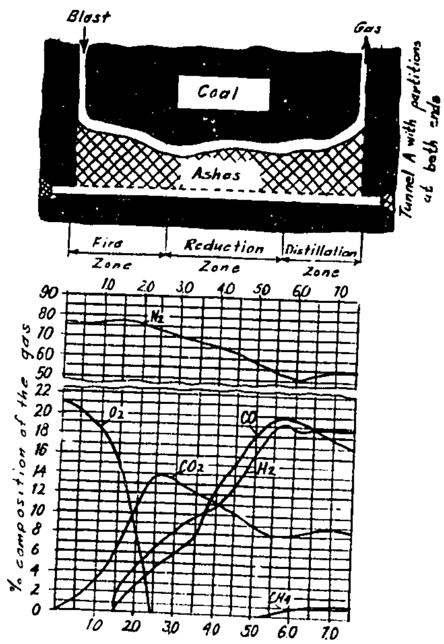

Figure 4. The Principles of the Flow Method, and Gas Composition

In the first zone, the so-called fire zone, which is about 2 meters in width, coal is oxidized to carbon dioxide; the high oxygen content of the blast makes it impossible for carbon monoxide or hydrogen to be formed here. Therefore, fuel gas is not yet formed here. In the next zone, the so-called reducing zone, the reduction of carbon dioxide to carbon monoxide occurs, and considerable amounts of hydrogen are also formed, depending on the moisture content in the neighboring layers and in the coal, and on the degree of degasification of the unburned coal.

In the third zone, the so-called degasification zone, the carbon dioxide content of the gas undergoes no further change, but the gas is enriched by the degasification of the coal front. The largest amount of coal is burned in the first zone, and it is therefore necessary to change the direction of the blast periodically to prevent asymmetrical burning out of the block. The greatest advantage of this method is the small amount of preparatory underground work. The flow method was tried out in Gorlovka. From the time when cheaply produced oxygen began to be used at this station, intensive studies have been made with an oxygen-enriched blast. The most satisfactory results were obtained with a blast containing 27-30 percent oxygen. The composition of the gas under those conditions is shown in Table 4.

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Table 4

CO_2	CO	H_2	CH_4	N_2	Calorific Value
10-12%	23-27%	12-15%	2-3%	43-47%	1,000-1,300 kcal/cu m by measurement 1,170-1,460 kcal/cu m by analysis

The blast was applied under a pressure of 3.5 atmospheres. Higher pressures gave poorer results. During one of the accidents, which caused temporary interruption of the process, the important observation was made that gas received in the absence of an air blast contained 60-70 percent hydrogen, while the nitrogen content was only 15 percent. This phenomenon was utilized in later operations, by alternating the periods in which the blast was applied with periods without the blast. The periods were of 4-6 hours' duration. Under these conditions, a daily output of about 25,000 cubic meters (two thirds of the total) of gas having a caloric value of 1,000-1,300 kilocalories per cubic meter was obtained, plus 12,500 cubic meters (one third of the total) of gas rich in hydrogen. The authors state that the process had and even course. Over an 18-month period of continuous production, a total of 9 million cubic meters of gas was produced, of which 7 million had a caloric value of 1,080 kilocalcries per cubic meter. Figures 5 and 6 present the gas composition and output obtained with alternating 4- and 6- hour periods. The diagrams show the gas composition in the periods with and without blast. During these tests, the blast used was not enriched with oxygen.

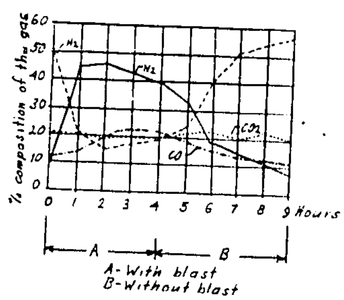

Figure 5. The Gas Composition in Relation to the Blast Periods in the Flow Method

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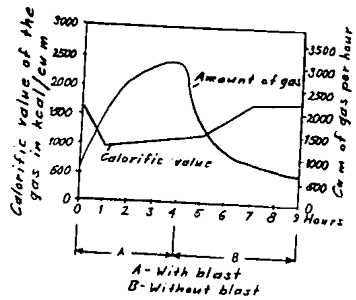

Figure 6. Calorific Value of the Gas in Relation to the Blast Periods in the Flow Method

Gas rich in hydrogen was obtained in the 4-hour period in which the blast was not applied. The gas composition is given in Table 5.

Table 5

CO_2	CO	H_2	CH_4	N_2	Calorific Value
20.3%	11.7%	44.7%	--	23.3%	1,600 kcal/cu m

Sheklin, Semenov, and Galinker present the precentage composition of the gas obtained when a blast containing 35-percent oxygen is used. The gas composition during the nonblast period is given in Table 6, and during the blast period, in Table 7.

Table 6

CO_2	CO	H_2	CH_4	N_2	Calorific Value
18%	15%	49%	4%	14%	2,090 kcal/cu m

Table 7

CO_2	CO	H_2	CH_4	N_2	Calorific Value
18%	15%	20%	3%	44%	1,220 kcal/cu m

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The occurrence of the gas rich in hydrogen is explained by the diffusion of hydrogen during the blast period into the crevices in the coal and the adjoining rocks, and its subsequent liberation when pressure diminishes after the blast is discontinued. In 1936, no steam was added to the blast in Gorlovka. Later, however, a blast composed of oxygen-enriched air and steam was applied, which resulted in a gas with calorific value of 2,620 kilocalories per cubic meter. After purification, its calorific value increased to 3,020 kilocalories per cubic meter.

The Drill Method

During the experiments in Lisichansk, it was established that the gas obtained was of poor quality as a result of poor air circulation. To obtain gas with a calorific value of 1,300-1,800 kilocalories per cubic meter, the gas has to be received through passages leading from the reaction area to the earth's surface. The best gasification conditions obtain if the drillings reach the inside of the layer, which causes the coal located between the two bottom outlets of the shafts to be gasified to a great extent. During the experiments on the Lisichansk block, conducted by the Donets, Scientific Research Coal Institute, the burning was begun in an opening drilled into the coal, into which air was blown. The coal forming the walls of this opening then underwent gasification and yielded fuel gas as a product. Gasification may be continued by this method only as long as the diameter of the drilled opening does not increase to several times its original dimensions. On the basis of the above observations, the so-called drill method was developed.

The application of this method necessitates the construction of two parallel tunnels, running lengthwise along the layer and serving to introduce the blast and to receive the gas. The tunnels are connected at right angles with a large number of parallel drilled openings, each 10 centimeters in diameter.

These openings cut across the entire width of the strip lying between the two tunnels, which run lengthwise. The tunnels are connected with the earth's surface by two shafts 60 centimeters in diameter, one for introducing the blast, and the other for receiving the gas. The length of the drilled openings was limited by the range of the drilling equipment to a maximum of about 100 meters. These openings are drilled at 5-meter distances from each other, and are equipped with valves at the entrances and with iron braces at the exits. For opening the entrance valves and for electrically igniting the coal in the openings, remote-control equipment is installed. The openings are ignited either consecutively or in small groups. The process is so conducted as to gasify the maximum possible amount of coal, while maintaining an even flow of gas. Figure 7 shows this kind of arrangement, containing a central blast tunnel and two gas-receiving tunnels placed at the two outer sides of the block.

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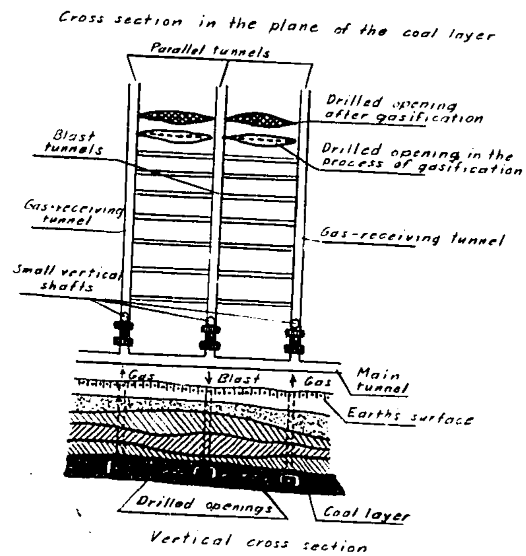

Figure 7. The Drill Method

Figure 7 also shows two openings that have already been gasified and two others in the process of gasification. This gasification method and similar ones which may be regarded as intermediate between the drill and flow methods have been successfully applied in Lisichansk and in the Kuznetsk and Moscow, basins. This method is particularly advantageous for horizontal deposits, or ones with only a slight dip, especially where the roof is porous. Zuravlev proposes that the tunnels be placed not in the layer itself, but either above or below the layer. The data concerning the application of this method in the Chelyabinsk area state that 2 cubic meters of gas, with a calorific value of 1,500 kilocalories per cubic meter, were obtained per kilogram of coal. Because of the necessity for considerable preparatory underground work, the drill method is recommended only where other methods fail. This method was applied in Lisichansk, and operated in such a way that an air blast was alternated with a steam blast at 20-minute intervals.

Table 8

CO_2	CO	H_2	CH_4	N_2
21.9%	15.0%	50.1%	5.4%	7.0%

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The average calorific value of the gas was 2,200 kilocalories per cubic meter, and the calorific value computed on the basis of analysis was 2,330 kilocalories per cubic meter. The composition of generator gas and of water gas obtained in this process is presented in Table 9.

Table 9

	CO_2	O_2	CO	H_2	CH_4	N_2	Calorific Value
Generator gas	11.0%	0.2%	12.0%	12.0%	5.0%	59.8%	940 kcal/cu m
Water gas	23.8%	0.0%	14.0%	44.5%	5.8%	11.8%	2,060 kcal/cu m

The Filter Method

The above method was proposed by the Power Engineering Institute of the Academy of Sciences USSR after investigating the Moscow Basin lignite deposits, when it appeared that, under certain conditions, they were sufficiently permeable for gas. This method is based on the phenomenon that, when heated, the lignite shrinks and forms cracks which permit the passage of gas. Advantage is taken of this phenomenon in the filter method of gasification. The method consists of drilling from the earth's surface a number of openings arranged in concentric rings spaced 18-37 meters apart, or arranged in some other regular pattern (see Figure 8).

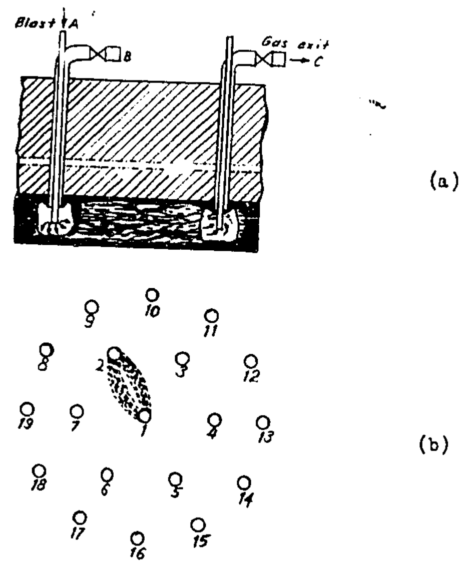

Figure 8. The Filter Method

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The lignite on the bottom of the drilled opening (No 1) is ignited either electrically or by means of throwing down glowing charcoal. Burning is maintained by supplying air or oxygen through a centrally placed pipe A.

Initially, the products come up through the outlet B. Then, after the lignite layer is heated and cracks and crevices are formed, it becomes possible for the gas to pass to the neighboring drilled opening (No 2), in which the lignite has been ignited in a manner similar to that used in No 1. Figure 8 illustrates the flow of the gas. As soon as the lignite located between the two openings is gasified, No 2 is shut, and the next opening, No 3, is put into operation (Figure 8b).

In this manner, the entire drilling area should be completely exploited. The Moscow Basin underground gasification station, put into operation in 1938, is still operating by this method. The gas produced has a calorific value of 900 kilocalories per cubic meter, with a composition as given in Table 10.

Table 10

CO_2	CO	HC_4	H_2	H_2S
14-16%	8-10%	1%	17-20%	2%

Certain modifications of the above method were later proposed. For instance, Yefremenko and Talizhin describe a method wherein three concentric rings of openings reach into the coal layer. The heads of the individual openings are connected within each ring. Air is forced into the center ring under a pressure of 5 atmospheres, while oxygen is forced into the outer ring under a pressure of one atmosphere. The authors state that the cost of all preparatory labor is only 15-20 percent of that of other methods. Various intermediate methods between the filter and flow methods were proposed for level layers, in which the flow method alone cannot be used because of the danger of the roof collapsing. For instance, Lavrov, Farberov, and Pitin have proposed a method in which the openings are arranged in a checkerboard pattern. The field to be gasified is divided into squares by vertical openings drilled from the surface to the layer, and these are subsequently connected by horizontal drillings. Chukhanov and Sakhaydak describes a set of shafts connected within the layer by horizontal drillings. The gasification is started by the flow method, using a horizontal opening as the fire tunnel. When the horizontal openings become blocked by falling rock, ashes, and slag, the gasification is not interrupted, as the adjacent coal is sufficiently cracked and porous to permit the continuation of the process by the filter method.

TECHNICAL PROBLEMS IN UNDERGROUND COAL GASIFICATION

Drilling Methods

Much attention has been given to devising methods by which the necessary underground preparations could be made without resorting to actual underground labor. The drilling methods generally used in the USSR were not adequate for performing slanting drillings, or for making the underground connections between the drilled openings. Kirichenko states that for drilling 75-meter openings in the coal layer for the purpose of placing explosive charges, a Siemens-Schuckert column-type drill crane was used, and also a Krelius crane, but neither was particularly well suited to that purpose. The same writer states that the

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Korfman drill crane (Germany) and the PSB (USSR) were used because of their durability and suitability for work connected with underground gasification. The machine should be driven by an electric motor, and should be capable of drilling both in dry and in flooded layers, producing openings up to 225 meters, with diameters of 30 - 35 centimeters, at angles ranging from 0 to 90 degrees. The drill should also be equipped with apparatus which would permit drilling even in an unevenly deposited layer. To obtain the desired cross connections, the following methods were used: hydraulic, consisting of applying water under high pressures; filter, consisting of exploiting the permeability of the layer by gases; and electrical, consisting of passing a current between two electrodes placed in the layer, which caused the burning out of the desired opening. It has also been recommended that attempts be made to use a stream of oxygen to burn out the desired opening.

Construction Work

With the flow method, steel props are necessary in the opening through which gas is received, while in the blast shaft and tunnels, wooden props can be used. If the system of periodic alternation of the direction of the blast becomes accepted in the flow method, steel props would become necessary in all the shafts.

The type of construction work depends on the form of the coal deposit, and its porosity. In the initial attempts, when brick passages were built for conducting the gas, many difficulties were encountered in obtaining the gas. In connection with this, the use of gas pipes was tried. In 1939, there were no suitable valves for underground operations under remote control. This resulted in the necessity of obtaining valves which would be suitable for the drill method.

Determination of Location of the Fire Head

In the flow method, the coal is burned out asymmetrically, which makes it necessary to change the direction of the blast periodically. It is very important to be able to determine from the earth's surface the depth and the shape of the fire head. Many methods have been worked out: electrical methods, consisting of measuring the unimpaired portion of a cable placed in the shaft; acoustic methods, based on the phenomenon of the reflection of sound from the fire boundary; measurements by means of thermocouples placed in the openings; and geophysical methods.

The Problem of Adjacent Layers

The layers adjacent to the degasification zones have presented many problems, since the temperature of the process depends on the conductivity, plasticity, and the melting of these layers.

The presence of adjacent limestone layers is disadvantageous, since their decomposition may increase the CO_2 content of the gas. If the adjacent layers are porous, special steps have to be taken in order to isolate the layers undergoing degasification. In both cases, the drill method may be applied. A classification of coal deposits with respect to their suitability for underground gasification has been proposed.

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Thermal Phenomena in Underground Gasification

The filter method has been very successfully applied in the gasification of lignite in the Moscow Basin, because of its high content of ash which has suitable properties.

When this lignite is burned at temperatures below 1,200 degrees centigrade, the ashes are porous, and they retain the shape and form of the layer. This is sufficient to support the ceiling of the deposit, without disturbing the course of the gasification. At temperatures of 1,300-1,400 degrees centigrade, the ashes lose their porosity and at 1,500 degrees centigrade they float above the layer of unburned lignite, which impedes gasification and creates the danger of the roof collapsing. The behavior of the ashes is of particular importance where the angle of dip of the layer is less than 45 degrees. If the angle of dip is greater, the ashes flow into the previously burned-out empty spaces underneath the fire zone, which makes it possible to maintain a continuous blast to the fire head. Heat losses caused by the conductivity of the coal layer and of adjacent layers are negligible; large losses may result from the presence of considerable quantities of water.

The Use of Oxygen

By adding oxygen to the blast, it is possible to decrease the relative nitrogen content in the gas and to obtain higher temperatures in the reaction zone. In this way, a better proportion of carbon monoxide to carbon dioxide should also be obtained. The gas yield of the coal should also be increased. Table 11 shows the percentage composition of gas obtained in Gorlovka under the application of blasts with varying amounts of added oxygen.

Table 11

	Gas Composition (%)						Calorific Value (kcal/cu m)
O_2 Added (%)	CO_2	O_2	CO	H_2	CH_4	N_2	
21	8	0.2	12	14	2.5	63.3	960
30	12	0.2	20	19	3.5	45.3	1430
50	15	0.2	25	23	8.0	28.8	2080
70	20	0.2	28	30	10.0	11.8	2540

In Gorlovka, a blast containing 27-30 percent oxygen was most frequently used. The use of oxygen increases production costs threefold. Large-scale oxygen production and the use of oxygen-enriched air have become the subject of intensive study in the USSR. Considerable efforts have been made to adapt the Kapitsa expansion turbine for industrial purposes.

Productivity of the Process

In the initial attempts at underground gasification, only a small fraction of the coal deposit underwent gasification. The reason for that was the collapse of the roof after only partial burning out of the layer, which permitted the air to escape from the reaction area. The gas produced would then mix with

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the air. Afterward, because of better-developed blowing techniques, the oxidation of the gas by the excess of unreacted air was limited. The flow method is advantageous from the point of view of avoiding coal losse but it requires appropriate running of the operation so that stray air currents under the blast, and cave-ins, are avoided. When the flow method is applied to level deposits (Moscow and Kuznetsk basins), coal losses result. Melted ashes cover the lower coal layers, which are then prevented from coming into contact with the blast. This was corrected by conducting the gasification at lower temperatures, below the melting point of the ashes.

Using underground gasification, as much as 80-90 percent of the coal may be utilized, while in mining only 60-70 percent of the coal is exploited.

INDUSTRIAL USE OF UNDERGROUND GASIFICATION IN USSR

The problem of underground gasification was part of the program covering the industrial development in the Second and Third Five-Year Plans in the USSR. The Third Five-Year Plan envisaged the supplying of gas, obtained by the underground gasification method, to power stations, chemical plants, and communal installations. If the operating costs of an electrogenerating plant, coupled with an underground gasification station, are compared with the operating costs of such a plant using generator gas or coal-burning boilers, it appears that with the use of underground gasification stations, the production costs are lowered by 50-62½ percent. The gas rich in hydrogen, which is obtained during the nonblast period of the flow method, is suitable for the synthesis of liquid fuels by means of the Fischer-Tropsch method, and for ammonia synthesis (after previous removal of the carbon monoxide). Yefremenko and Talizhin recommend the production of sulfur and thiosulfate at a plant for gas purification. It has been proposed that the gas produced in the Moscow Basin be transmitted by means of a 200-kilometer pipeline to the Moscow region, after previously removing from it the carbon dioxide and enriching it catalytically. The transportation cost for gas of low calorific value is placed at 8-10 kopeks, per kilometer, computed in units equivalent to one ton of coal. The transportation cost is high-calorie gas would be lower, and would amount to 6-8 kopeks per kilometer. It costs 10-20 kopeks to transport one ton of coal one kilometer (in the Donets Basin the figure was 11.3 kopeks in 1937).

The problem of underground gasification is one of great social importance to the USSR, because of the possibility of limiting, or even to a large extent eliminating, underground labor. It was announced in 1941 that, while in Russian coal mines 70 percent of all workers are working underground, in underground gasification plants they constitute only 15 percent of the crew. Aside from this, the average work output per worker, computed in terms of heat units produced, increases as much as tenfold with the application of the underground gasification method. The average output per worker increased from 30 tons of coal a month, when mining methods were used, to a quantity equivalent to 100-120 tons per month (converted to heat units), with underground gasification. Using large installations, it is possible to attain a quantity equivalent to 500-600 tons per month.

Underground labor requires 5-6 times fewer workers in underground gasification plants than in coal mines (for the same heat value produced).

The investment costs for an underground station are placed at 60-70 percent of the costs of surface gasification, according to many publications.

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In the flow method, surface operations constitute 80-90 percent of the work, and underground preparations of the layer constitute 14-15 percent. With the filter method, the costs should be 15-20 percent lower. For a combine consisting of an underground gasification station and an electrogenerating plant, the investment costs are given at 15,000 rubles per kilowatt of power, and the cost of production amounts to 4-6 kopeks per kilowatt-hour, including wages and transportation costs amounting to 7-10 percent of the total. The cost of an oxygen-producing unit is given as 70 percent of the total cost, while the production costs of gas produced by means of oxygen-enriched blast are three times as much as the production costs of gas obtained with an ordinary blast.

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